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On the Systematic Errors of the Greenwich North Polar Distances.

By W. H. M. Christie, Esq.

(*Abstract.*)

The long series of observations of N.P.D. made at the Royal Observatory, Greenwich, under the superintendence of Sir G. B. Airy from 1836 to 1878 is discussed in this paper with reference to the systematic errors in the flexure and R − D corrections, in the refractions and in the adopted latitude. It is pointed out that the coefficient of refraction cannot be determined with sufficient accuracy from circumpolar stars, since refraction produces on stars at different distances from the pole only a differential effect which is comparatively small as far as Z.D. 75°, at which point the law of refraction begins to be somewhat uncertain; and that this effect is masked by uncertainty in the flexure and by the probable errors of the observations. On this view the determination of refraction must depend mainly on observations of southern stars made at Greenwich and at southern observatories, for which the effects of refraction are additive.

In the series of observations 1836-1878 the instrumental conditions have been twice changed, involving changes in the horizontal flexure and R − D correction, and from this it is inferred that the R − D correction is probably connected in some way with flexure, and not with any abnormal refraction.* The observations may be divided into three periods: (1) 1836–1849 made chiefly with the Troughton Mural Circle, for which there was no flexure or R − D correction; (2) 1851–1865, with the Transit-Circle before the central cube was perforated: the flexure correction was + and the R − D correction − for south stars; (3) 1866–1878, with the Transit-Circle after the central cube was perforated: the flexure correction was −, and the R − D correction + for south stars. After the piercing of the cube the observations of the collimators in the determination of flexure were made through the cube, instead of with the Transit-Circle raised. A table is given of the annual results for co-latitude and corrections to the position of the ecliptic: and in order to make these comparable they are corrected so as to reduce them to the same refractions (Bessel's *Tabulæ Regiomontanæ*) throughout; and in the case of the result for the ecliptic to the same co-latitude 38° 31′ 21″·90 and to Le Verrier's value of the obliquity.

The latitude determinations from circumpolar stars are discussed in four groups:—(1) 1840–1847, with the Troughton Circle; (2) 1851–1861, with the Transit-Circle, when the old law $a + b \sin z$ for R − D was used; (3) 1862–1865, with the Transit-Circle, when the new law $a + b \sin z \cos^2 z$ was used;

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* In a paper on the "Discordance of Direct and Reflexion Observations" (*Memoirs*, vol. xxxii.) the Astronomer Royal concluded from a discussion of the latitude determinations 1836–1860 that the R − D correction probably depended on the shutter opening; but this was written before the piercing of the Transit-Circle cube.

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(4) 1868–1876, with the Transit-Circle after the piercing of the cube, when the diminution in Bessel's refractions (·00531 × refraction) proposed by Mr. Stone was adopted. Tables and curves are given showing the excess of N.P.D. above the Pole, or twice the error of assumed co-latitude, from groups of stars at different distances from the Pole for these four periods, with Bessel's refractions and the old and new laws for R—D respectively, and with Mr. Stone's diminished refractions and the new law for R—D. It is pointed out that for the first three periods, 1840–1847, 1851–1861, and 1862–1865, Bessel's refractions and the old law for R—D on the whole give better results at any rate as far as N.P.D. 40°. But as Mr. Stone had based his diminution of the refractions on the observations 1857–1865, these are discussed separately, giving residuals for this particular period which, though differing somewhat from those given by Mr. Stone, would be decidedly improved by a diminution of the refractions. The amount of this diminution depends to some extent on the adoption of the new law for R—D: with the old law it would be only one-half that found by Mr. Stone. But the strength of this evidence in favour of diminished refractions is shaken somewhat by the results for the longer period 1851–1861, and still more by those with the Troughton Circle, 1840–1847, which are unaffected by flexure and R—D corrections. Further, it is pointed out that Mr. Main's exhaustive discussion of the observations 1836–1854 (*Memoirs*, vol. xxvi.) shows that as far as Z.D. 82° Bessel's refractions unaltered represent satisfactorily the observations of northern as well as of southern stars, and that down to this limit no correction of Bessel's refractions of the *Tabulæ Regiomontanæ* is admissible for these observations.

The results for the period 1868–1876 indicate such a large error at N.P.D. 20° (where the curve runs up almost to a cusp) that no certain conclusion can be drawn from them as regards the refractions. Slightly more accordant results are given with Bessel's refractions unaltered and the new law for R—D. If the observations above Pole at N.P.D. 20° (where the R—D correction is well determined) are assumed to be free from error, a correction of nearly + 1″ would be required at Z.D. 60° N. to the observed zenith distance (numerical).

A comparison is next made of the co-latitudes deduced from observations of circumpolar stars and of the Sun, the latter being inferred from the ecliptic investigation in which the correction to the mean of the observed N.P.D.'s of the Sun throughout the year is given. The following are the results corrected for error of thermometer:—

	WITH BESSEL'S REFRACTIONS. Co-latitude		WITH STONE'S REFRACTIONS. Co-latitude	
	from stars.	from Sun.	from stars.	from Sun.
	″	″	″	″
1836–1849	21·85	21·90	21·61	22·40
1851–1865	21·87	21.27	21·63	21·77
1866–1878	21.83	21·84	21·59	22·34

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The balance of evidence is by a majority of 2 to 1 against any diminution of the refractions. But in the period 1851–1865 there is a large discordance in the results from the Sun, which seems to indicate an error at Z.D. 60° S. before the piercing of the cube, analogous to that at Z.D. 60° N. shown by circumpolar stars after the piercing.

A table is given exhibiting the comparison of the various Greenwich Catalogues with the Cape (1860) and Melbourne (1870) Catalogues in extension of that given by Mr. Downing (*Monthly Notices*, vol. xxxix. p. 133) for the first Seven Year Catalogue. It is pointed out that the use of Mr. Stone's diminished refractions in the Nine Year Catalogue has produced intolerable discordances, which are removed by the substitution of Bessel's (with Main's corrections below Z.D. 82°), and that the comparisons of the Greenwich first Seven Year Catalogue (1854–1860) with the Cape and Melbourne catalogues seem to show that a negative correction is required to the Z.D.'s south of the zenith, such as appeared to be indicated by the observations of the Sun 1851–1861.

The question of the obliquity of the ecliptic is discussed with special reference to the value of the secular variation. Bessel found the value $-0''.457\,t$ from observations 1755–1815, whilst Le Verrier adopted $-0''.476\,t$ based entirely on his theory of the Sun, rejecting the value $-0''.4576\,t$ which he had previously found from observations 1755–1846. Under these circumstances the following comparison has been made of Le Verrier's and Bessel's formulæ respectively with the Greenwich results:—

	With Old Law for R–D. Corrections to		With New Law for R–D. Corrections to	
	Le Verrier.	Bessel.	Le Verrier.	Bessel.
	"	"	"	"
1836–1849	+0·21	+0·22	+0·21	+0·22
1851–1865	+0·16	−0·11	+0·32	+0·05
1866–1878	+0·20	−0·40	+0·04	−0·56

It appears from these quantities that the Greenwich observations are well represented by Le Verrier's value of the secular variation and not by Bessel's, and that the old law for R—D, $b \sin z$ gives more accordant results than the new law, $b \sin z \cos^2 z$. It is pointed out that the constant correction $+0''.19$ to Le Verrier's obliquity given by the Greenwich observations represents very nearly the effect of the difference $(+0''.26)$ between the refractions of the *Fundamenta* (which Le Verrier appears to have used) and those of the *Tabulæ Regiomontanæ* now used at Greenwich.

In conclusion it is urged that every effort should be made to obtain observations of stars by reflexion as near the horizon as practicable in order that the R—D correction may be determined for large zenith distances, and that the determination of horizontal flexure should be checked by other methods, since the adop-

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tion of the old law, $b \sin z$ for the R—D correction, virtually neutralising the flexure correction, would imply that the latter was erroneous. As regards the question of refraction, a comparison is given between the temperatures of the air at different altitudes as observed by Mr. Glaisher in his balloon ascents and those assumed by Laplace, Bessel and Lubbock in their theories of refraction; and the inference is drawn that Bessel's refractions may be too large for large zenith distances, through his assumption of an erroneous law for the constitution of the atmosphere, though they may be sensibly correct as far as about Z.D. 80°.

Description of a proposed new Uniform Pressure Clock.

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The object of the present paper is to submit to the consideration of the Royal Astronomical Society a means of preventing the changes in the density of the atmosphere from reaching a clock and affecting its rate, by enclosing the clock in an air-tight case in which a uniform pressure may be maintained.

The late Mr. Carrington endeavoured to attain the same end by having a case of copper made for a clock of the ordinary construction; but he does not appear to have been entirely successful. The necessity of winding the clock with a winder passing through a stuffing-box seemed to be a source of frequent trouble, and the repeated breaking of the plate glass covering the dial was also an annoyance. I venture to think the method I am about to describe promises a better result.

I propose, in the first place, to mount the clock movement and hang the pendulum on a massive bracket projecting like a shelf from the wall to which it is fixed; covering both with a bell-glass like the receiver of an air-pump.

To the under side of the shelf I propose to fix a similar bell-glass, but one so elongated as to take in and enclose the pendulum. The upper and under surfaces of this shelf, which would form the seat-plate of the clock, would be worked to a true plane, and the bell-glass covering the movement would have a ground edge, so that the joint made here would be air-tight. It would probably be very difficult to grind the edge of the lower glass on account of its depth, therefore it would be better to fasten to it, by a suitable cement, a metal ring previously worked to a true surface, and thus obtain an equally good joint with the under side of the seat-plate. The space thus enclosed by these glass vessels would form the clock-case, and would be placed in connection with an air-pump by a tube screwed into the seat-plate. Now, setting aside for the moment the necessity of winding, and assuming the above provisions to be successfully carried out, we should have a clock going in an air-tight case in which the pressure may be